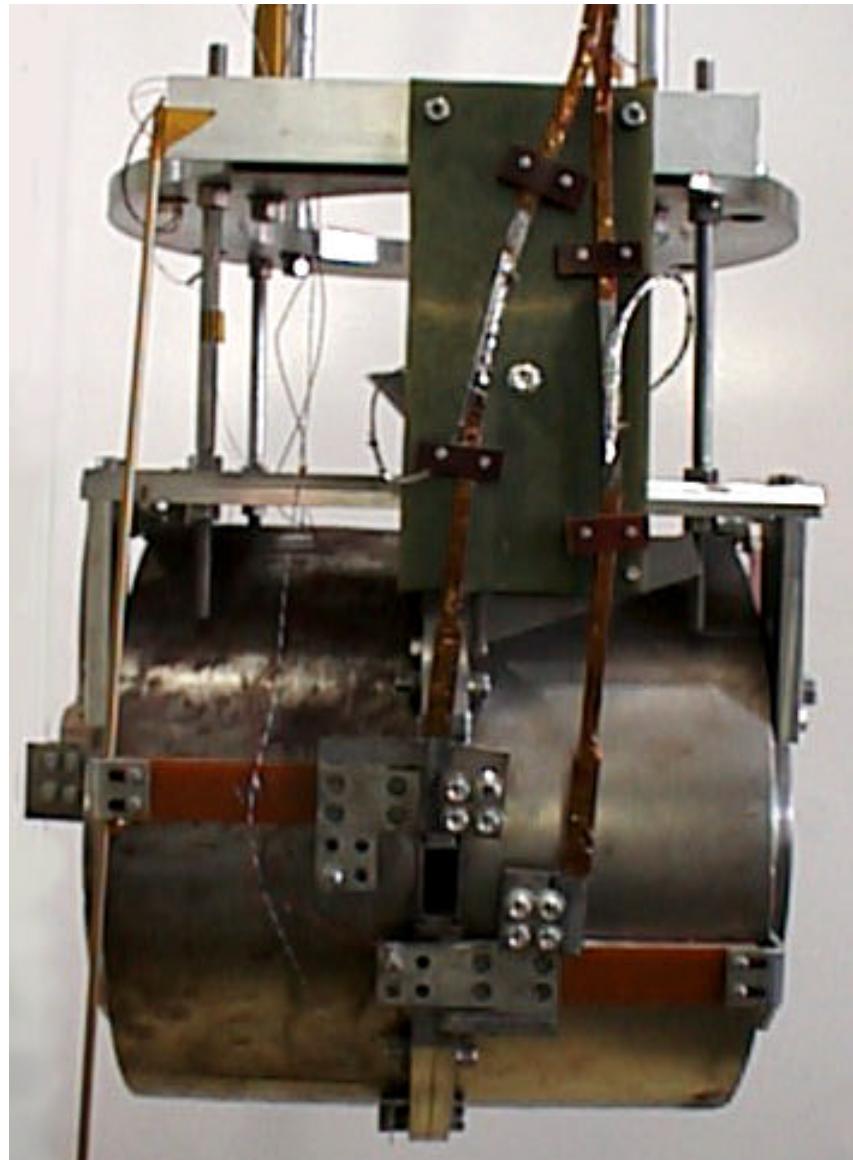


Quench Protection Consideration

M.Wake/KEK



Temperature Rise after A Quench

$$RI^2 = C \frac{dT}{dt}$$

$$\int_0^\infty I^2 dt = S^2 \left[\frac{r^2}{(r+1)^2} \int_{4.2}^T \left(\frac{C_{Cu} m_{Cu}}{r_{Cu}} \right) dT + \frac{r}{(r+1)^2} \int_{4.2}^T \left(\frac{C_{Sc} m_{Sc}}{r_{Cu}} \right) dT \right]$$

MIITS = f(cross section, copper ratio, temperature)

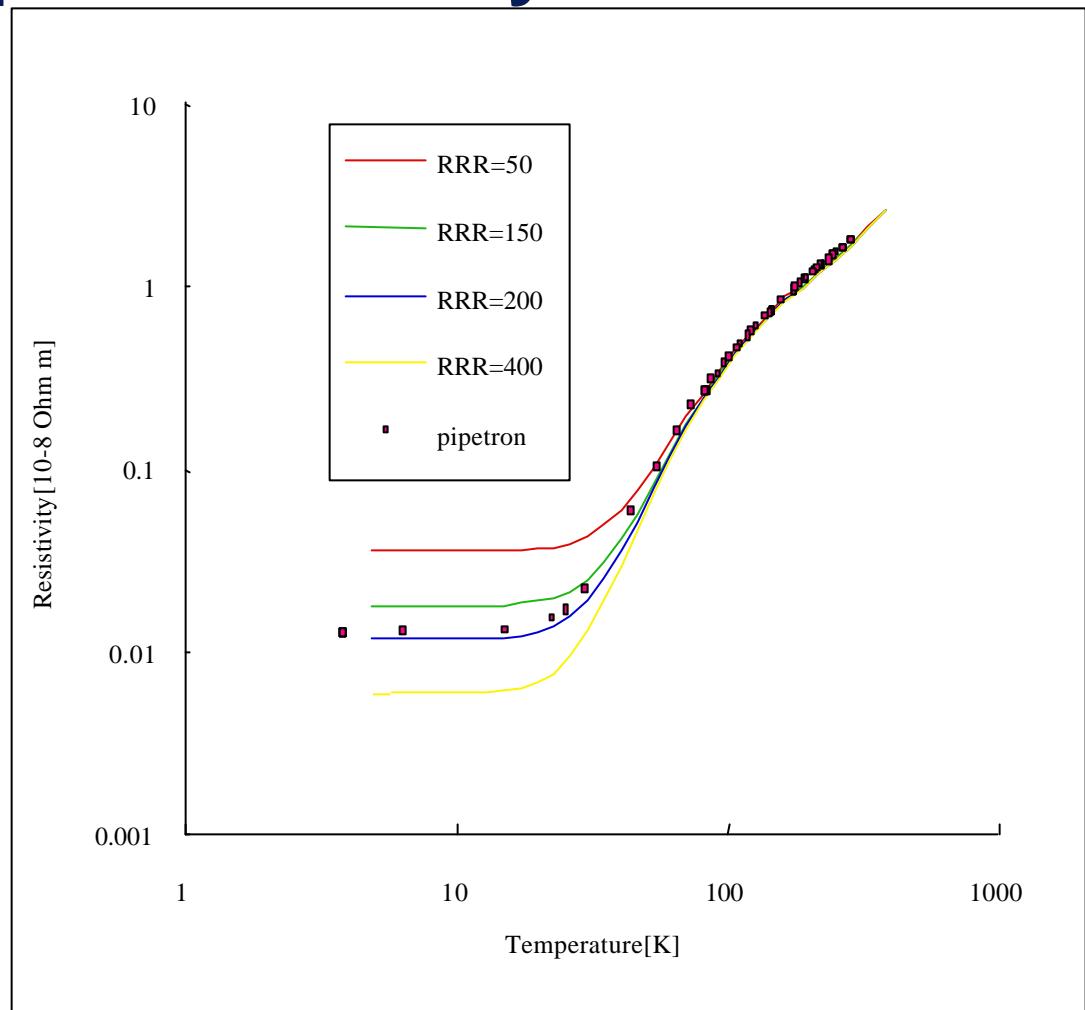
S:conductor cross section

r: Cu/Sc ratio

Copper Resistivity

$$R = R(T) + \frac{R(273)}{RRR}$$

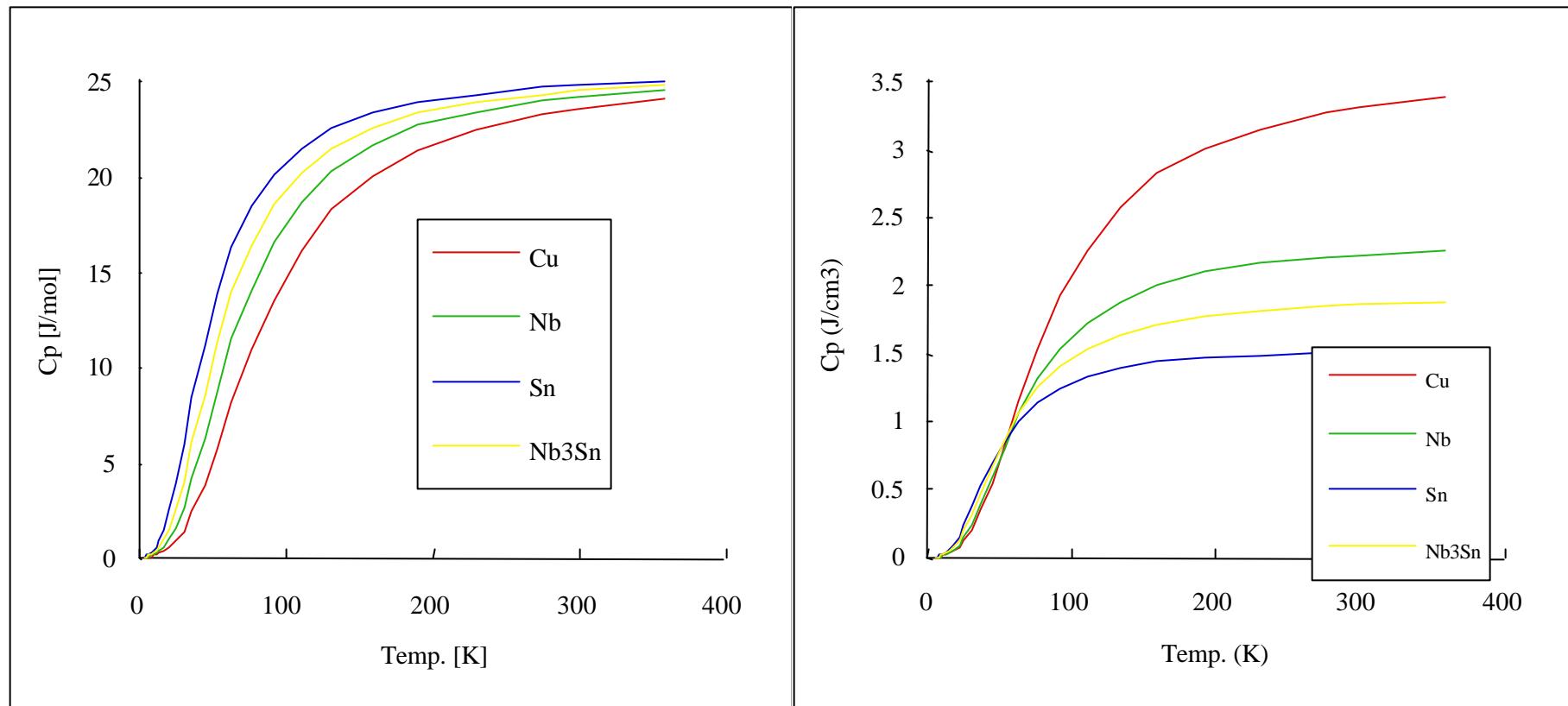
$$\begin{aligned} \log R(T) &= \\ &-9.600976 \\ &-12.52445(\log T) \\ &+8.309361(\log T) \\ &-1.583458(\log T) \\ &+0.0993132(\log T) \\ &[10^{-8} \text{ ohm } \bullet \text{ m}] \end{aligned}$$



M.C.Jones et al. (Cryogenics 18(1978)337)

Heat Capacity

$$C_v = 9R \left(\frac{T}{T_D} \right)^3 \cdot \int_0^{\left(\frac{T_D}{T} \right)} \frac{x^4 \exp(-x)}{(\exp(-x) - 1)^2} dx / Z$$



MIITS to Heat Up to 300K

RRR 300K survival MIITS for 1mm² conductor

Copper Ratio	70	100	130	160	190
0.852	0.0547	0.0582	0.0629	0.0675	0.0716
1.000	0.0598	0.0636	0.0687	0.0736	0.0781
1.200	0.0657	0.0699	0.0754	0.0807	0.0856
1.600	0.0750	0.0796	0.0858	0.0917	0.0971
2.000	0.0819	0.0869	0.0935	0.0999	0.1057
4.000	0.1004	0.1063	0.1141	0.1216	0.1284

RRR 300K survival MIITS for 1mm 28strand cable

Copper Ratio	70	100	130	160	190
0.852	26.4	28.1	30.4	32.6	34.6
1.000	28.9	30.7	33.2	35.6	37.7
1.200	31.7	33.8	36.4	39.0	41.3
1.600	36.2	38.5	41.4	44.3	46.9
2.000	39.6	42.0	45.2	48.3	51.1
4.000	48.5	51.4	55.1	58.7	62.0

MIITS Estimation

Stored Energy

$$U = \frac{B^2}{2m_0} D_{eff}^2 \frac{p}{4} L$$

Inductance

$$Lm = \sqrt{\frac{2U}{I^2}}$$

Time Constant

$$t = \frac{L_m}{V_{init}}$$

$$MIITS = I_q^2 t_{delay} + \int_0^\infty I^2 dt < I_q^2 t_{delay} + \frac{1}{2} t I_q^2 (\text{exponential})$$

$$MIITS = I_q^2 t_{delay} + \int_0^\infty I^2 dt < I_q^2 t_{delay} + \frac{1}{3} t I_q^2 (\text{linear})$$

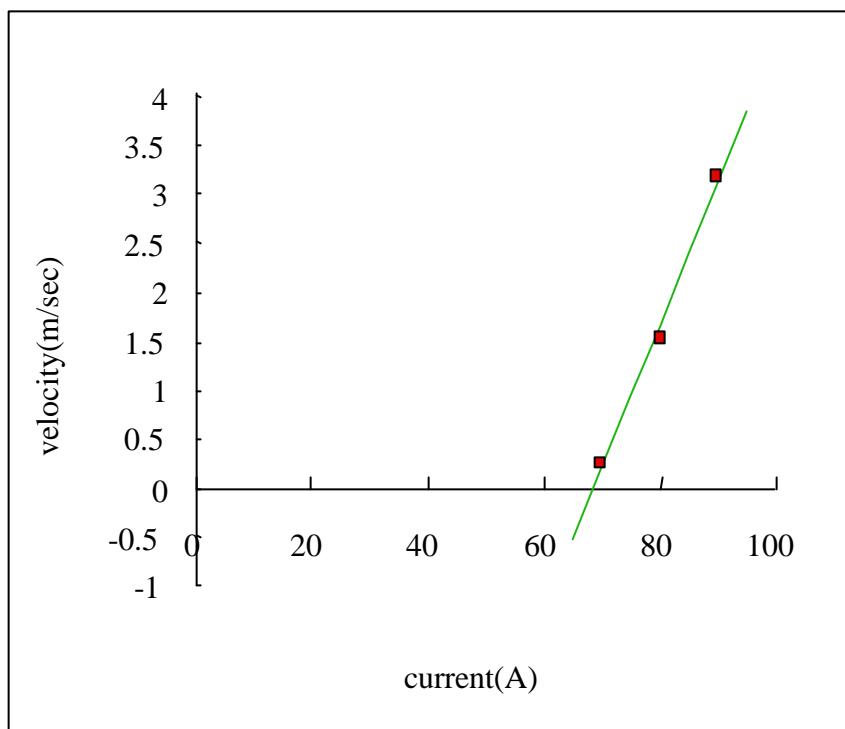
$$MIITS \approx I_q^2 t_{delay} + \frac{1}{4} t I_q^2 (\text{heater})$$

MIITS Estimated

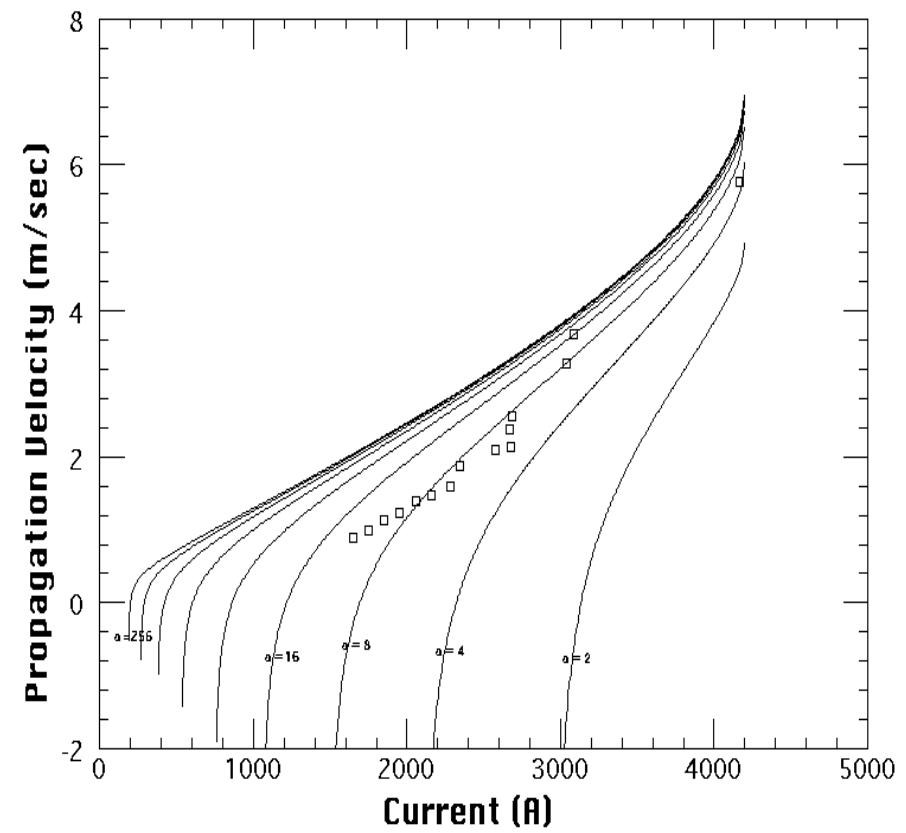
		VLHC Model	Tevatron	SSC	LHC
field	[T]	11.00	4.5	6.6	8.4
aperture	[m]	0.045	0.075	0.05	0.056
length	[m]	12	6	16	14
stored energy	[MJ]	2.687	0.625	1.592	2.831
operation current	[kA]	18	4.5	6.5	11.5
inductance	[H]	0.016585	0.0617	0.0754	0.0428
extraction voltage	[V]	500	500	500	500
time constant	[sec]	0.5971	0.5551	0.9798	0.9846
delay time	[sec]	0.05	0.05	0.08	0.08
delay MIIT	[MIIT]	16.20	1.01	3.38	10.58
exponential decay MIIT	[MIIT]	96.72	5.62	20.70	130.22
linear decay MIIT	[MIIT]	64.48	3.75	13.80	65.11
heated MIIT	[MIIT]	48.36	2.81	10.35	32.55
total MIIT	[MIIT]	64.56	3.82	13.73	43.13
300KMIITS	[MIIT]	62.0	4.39	17.24	46.60

Quench Propagation

Nb3Sn strand



Nb3Al Cable



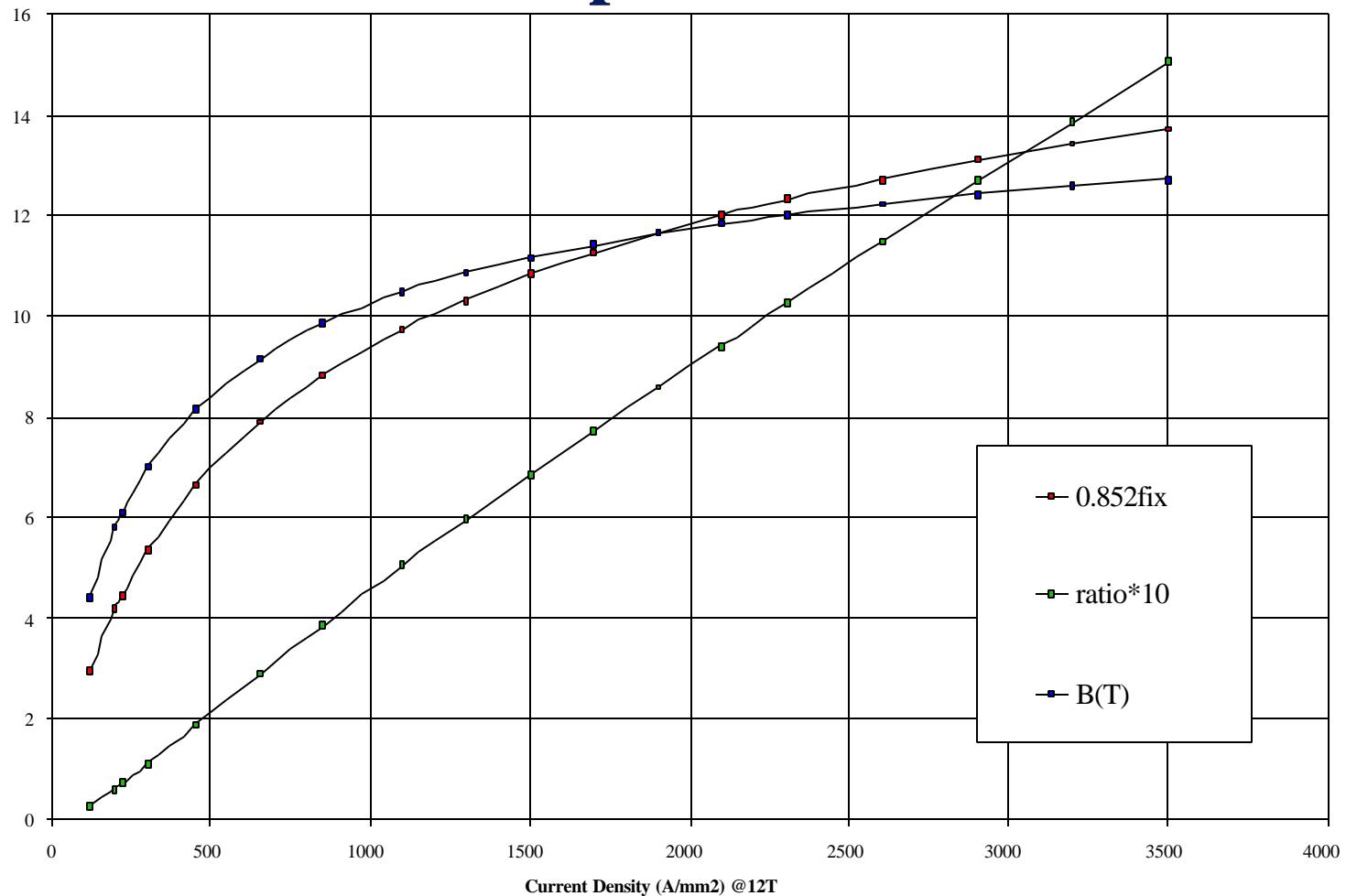
Magnet Design

$$I_c \propto \left(\frac{B_c - B}{300} + 1 \right)^3 - 1 \quad h \propto \frac{2r}{2r + w}$$

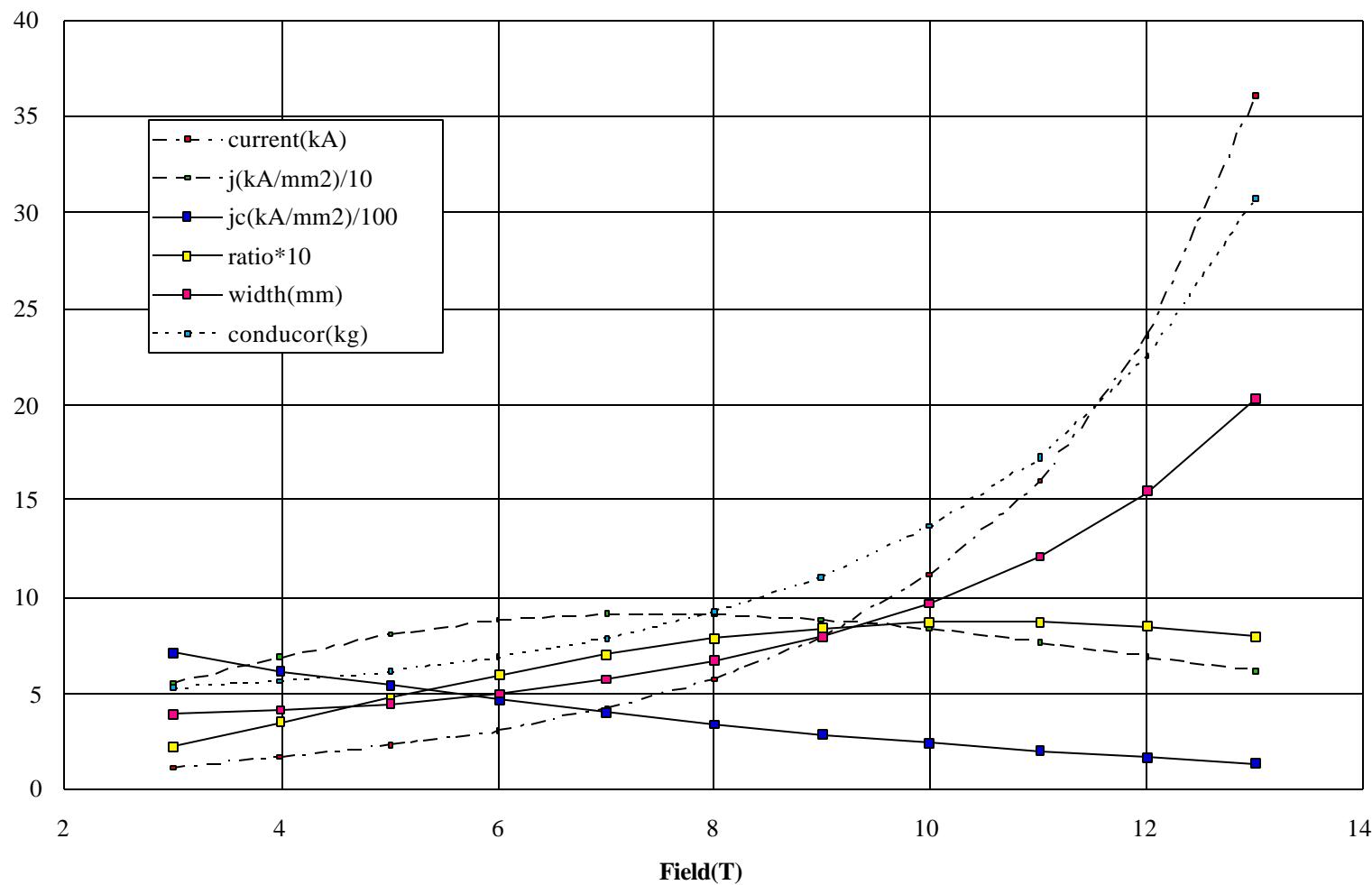
$$r \propto B^2 j_c$$

$$B = 0.8 j_w \sin(\theta) \left(1 + \frac{3r^2 + w^2 + 3rw}{3R^2} \frac{m-1}{m+1} \right)$$

Jc Dependence



Field Dependence



Conclusion

**A new approach for the quench protection has to be taken
for the VLHC**

Large stored energy

Large number of magnet

We can not be optimistic

**requires more copper
requires more reliability**

**It is necessary to be careful in the selection of design parameters
to be serious for the construction of an accelerator.**

operation field with reasonable cost

aperture with synchrotron radiation and field quality